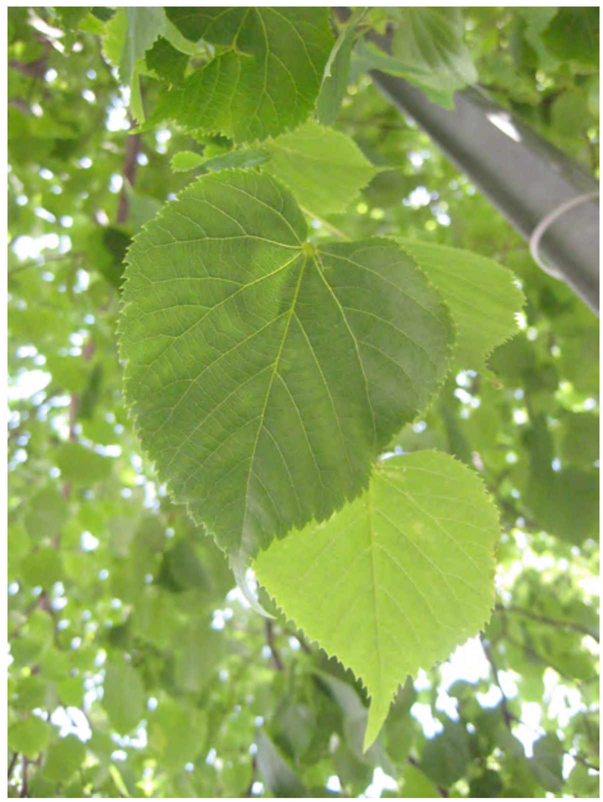
Selling the Urban Forest

Calculating the Environmental and Economic Benefits of Street Trees



Street trees along the west side of Beacon Street in Somerville, MA (*Pyrus calleryana* and *Tilia cordata*).
(image date: 15 May 2009)

Emily Bonifaci
Master of Landscape Architecture, 2010
bonifaci@gsd.harvard.edu

Harvard University
Graduate School of Design
6318, Richard T.T. Forman, Professor

19 May 2009

Introduction

An uncertain economy always encourages cities and their citizens take a hard, systematic look at municipal budgets, outlays, the value of resources, and the return on investments. Until about 15 years ago not much was understood regarding how investing in a city's street trees, or cumulatively the urban forest, could perhaps result in positive and *quantifiable* environmental, economic, and social benefits. Since, researchers, nonprofit groups, and city departments have developed a variety of models for understanding the costs and benefits of this "green infrastructure," using Somerville, MA's Mayor Joseph Curtatone's term. What they've catalogued is long list of valuable benefits of street trees, including reductions in stormwater runoff, increases in property value, and reductions in heating and cooling costs for urban residents. Further, the models now make an attempt to assess how much, in economic terms, these services are worth to municipalities in comparison with how much the cities are spending to plant and maintain their trees. One study of five U.S. cities found that for every dollar spent, between $1.37 and $3.09 were returned in benefits (McPherson et al., 2005). This precision of data can help make a case for increased investment and guide urban forest managers in resource allocation to minimize costs and maximize the benefits of their city's street trees.

Understanding the Benefits and Costs of Street Trees

A significant body of recent research examines the costs and the benefits of urban trees. These range from chemical services like air cleansing to physical services such as the interception of rainwater, reducing capacity requirements of stormwater infrastructure. However, these same street trees present some burden environmentally and economically for cities in terms of their emission of biogenic volatile organic compounds (BVOCs) and the cost of installation, leaf litter cleanup, and liability insurance related to trip-and-fall claims.

Perhaps the best known benefit of street trees is their ability to capture and sequester atmospheric carbon, reducing concentrations of CO_2, a greenhouse gas that contributes to climate change. Trees intake carbon during the photosynthesis process as they grow, releasing oxygen back out into the atmosphere. The absorbed CO_2 is stored in tree tissue both above ground and in below ground root biomass. Absorption and sequestration capabilities vary greatly by specimen (Nowak & Crane, 2000). Sequestration rates can range from 35 to 800 lbs. per year depending upon growth rate and a mature tree can hold up to 1,000 times more carbon than a young one (Gartland, 2008).

Trees also help remove a variety of other harmful pollutants from the air through absorption and dry deposition processes, including NO_2, O_3, SO_2, and PM_{10}. Urban street trees may be able to reduce ozone and sulfur dioxide by 20% (McDonald et al., 2007). Plants can also take up harmful nitrogen dioxide (a result of fossil fuel combustion as in car engines and energy generation) from the atmosphere and assimilate it into organic compounds, essentially creating their own nitrogen fertilizer. A tree's capability to do so depends on species, which vary in terms of assimilation and resistance to high levels of NO_2. Broadleaf deciduous trees, especially *Robinia pseudoacacia*, *Sophora japonica*, and *Populus nigra*, with their high biomass and fast growth rates, were found to be the best remediators of NO_2 in urban air (Takahashi, 2005). The value of the pollution removal capabilities of urban trees in Chicago in 1991 was placed at $1 million within the city limits and $92 million across Cook and DuPage counties (Nowak, 1994).

Particulate pollution is often categorized as PM_{10} (particulate matter which is 10 or fewer micrometers in diameter) although there is increasing evidence that human health issues are linked to even smaller particles, such as $PM_{2.5}$ (McDonald et al., 2007). Particulate pollutants pose ever more severe health risks in urban areas around the globe: a 1999 World Health Organization report estimated that more people die prematurely due to health complications related to particles released in vehicular emissions than from car crashes. Wooded areas capture particulate matter more effectively than any other land type due to leaf surface area and turbulence created as wind passes through (Beckett et al., 2000). Trees have the ability to capture pollutants through a process called dry deposition, in which gravity, Brownian motion, and interception allow particles to be captured on tree leaves and bark (Gartland, 2008). A 2007 study by McDonald et al. determined that, while anthropogenic abatement measures to reduce particulate pollution may be prohibitively costly, increasing tree cover to a theoretical maximum of 54% in West Midlands, U.K. could reduce PM_{10} concentrations by 26%, or by 200 tons per year (see figure 1). Other research has focused on identifying which species have the greatest effectiveness at capturing particulate matter. Beckett et al. (2000) assessed five different species (pine, maple, whitebeam, poplar, and cypress) and found that conifers had the greatest capture success due to their more complex foliage structure.

Trees can also help reduce pollutants from entering the atmosphere in the first place through their ability to reduce overall energy consumption within a community, resulting in fewer emissions from power production. In fact, this reduced energy use and the resultant lowered CO_2 pollution dwarfs the value of actual sequestration of carbon within trees (McPherson et al., 2005). Trees shading buildings, especially windows, results in decreased energy needs for cooling (up to 40% reduction observed, Akbari et. al. 1992 in Gartland, 2008). Street trees also help reduce overall urban air temperatures which are artificially heightened due to the urban heat island effect. Vegetation provides two primary services that reduce air temperature: shading structural surfaces that absorb and radiate heat (walls, roofs, roads, and sidewalks) and cooling of the air through evapotranspiration. A mature, well-watered tree can remove up to 960 MJ of heat on a daily basis (Gartland, 2008). Trees may also serve as windbreaks, allowing for reduced heating costs during cold winters (see figure 2). Finally, shade helps reduce temperatures in parked cars along streets and in parking lots that, in turn, results in lower evaporation hydrocarbon emissions from gas tanks and a reduction in emissions released at vehicle starting (Gartland, 2008).

Besides pollutant capture and reduction, urban trees have a litany of other benefits for both municipalities and individual residents. For example, the urban forest helps to reduce capacity needs of expensive stormwater infrastructure systems. By catching rainfall on their leaves and branches trees reduce the amount of water that hits the ground and becomes runoff. One study found that trees intercepted as much as 36% of the rainfall that hit them (Xiao et al., 1998 in Gartland, 2008). Trees also add to property value; a typical mature specimen is estimated to increase the sale price of a home by $5.53 per square meter of leaf surface area (Maco & McPherson, 2003). Other benefits of the urban forest include significant ecological services and aesthetic and quality of life improvements.

However, maintaining a sizeable, robust urban forest doesn't come without costs. Cities must pay for planting and maintenance, including pest and disease control, storm and leaf litter clean up, pruning, and liability insurance. McPherson, et al. (2005) found that five U.S. cities spent between $13 and $65 annually per tree. Surprisingly, pruning was the greatest expense while planting only accounted for 2-14% of outlays. There are environmental costs associated with street trees as well, primarily in the form of BVOC emissions, especially isoprene and monoterpene. Emission rates vary greatly among species and Berkeley, CA, a city with a large population of high emitters (ex. *Eucalyptus spp*., *Liquidambar styraciflua*, and *Platanus x acerifolia*), faces air quality costs of $0.57 per tree (McPherson et al., 2005). Planting low VOC emitting trees has been shown to reduce ozone levels in urban areas (Nowak & Crane, 2000). Further, the various environmental and economic paybacks listed above have been shown to counterbalance the effects of VOC emissions, resulting in a net benefit (McPherson et al. 2005).

Calculating the Value of the Urban Forest

It is precisely this sort of cost-benefit question that necessitates the use of complex models to understand the net value of street tree plantings. Even with a basic understanding of the complex benefits of trees, cities may be unlikely to promote large-scale investment without scientific cataloguing and analyses of their urban forests. Various computer-based modeling systems exist that allow urban forest managers to assess the structure and value of their trees. These include the USDA Forest Service's STRATUM (Street Tree Management Tool for Urban forest Managers) and UFORE (Urban Forest Effect Model) models, the Community Forest Inventory and Management Tool from the Urban Forest Ecosystems Institute, and American Forest's CITYgreen GIS program.

The UFORE and STRATUM models appear to have the highest use rates among municipalities nationwide and a variety of studies have been undertaken analyzing the urban forests of cities like Boston, Toronto, Philadelphia, and Baltimore. The UFORE model permits managers to understand their forests' structures and functions by allowing sampling input that quantifies species composition and diversity, tree density and health, leaf area, and biomass. These data, along with local pollution and meteorological information, allows UFORE to compute total BVOC emissions, carbon sequestration and storage, and dry deposition of air pollution (CO, NO_2, O_3, SO_2, and PM_{10}) along with percent improvement in air quality. For example, 1991 through 1996 UFORE analyses revealed that Atlanta had a canopy cover of 32.9% (9.4 million trees), Chicago, 11% (4.1 million trees) and Boston, 21%, (1.8 million trees), among others (see figure 3). The model also allowed for cumulative analyses of pollution removal capabilities of the trees in these cities. In New York City trees removed an estimated 1,821 metric tons of pollution at a $9.5 million in estimated value to society (see figure 4) (Nowak & Crane, 2000). Perhaps the most revolutionary component of the UFORE and STRATUM models is this ability to quantify actual dollar values of trees based on the services they provide to each particular city. STRATUM allows energy cost savings to be quantified by assessing local fuel costs, climate, and shade capabilities of the studied trees. Runoff reductions can be given monetary value through examinations of a city's stormwater infrastructure construction and maintenance costs (McPherson et al., 2005).

McPherson et al's 2005 study began with their contention that "measuring benefits that accrue from the community forest is the first step to altering forest structure in ways that will enhance future benefits." The researchers conducted an in-depth analysis of a sample of 30-70 randomly selected trees from each of five cities' most abundant species. Computer simulations were used to calculate energy savings and tree biomass was analyzed to estimate CO_2 sequestration. Monetary values were assigned to pollutant deposition calculations based on each city's societal value placed on clean air or damage values associated with pollutant concentrations and population size. Researchers also assessed stormwater runoff reductions and aesthetic benefits, like property value increases. The study found that benefits ranged from \$31 per tree in Glendale, AZ to \$89 per tree in Berkeley, CA with property value benefits making up the largest percentage for all cities but Bismarck, ND which received the largest benefit from runoff reduction. The study was also able to assess the amount each city spent per tree (ranging from \$12.87 to \$65 per year) and calculate with cumulative cost-benefit comparisons: ratios ranged from Bismarck's \$3.09 return on each dollar invested to Berkeley's return of \$1.37.

Maco & McPherson's (2003) study of Davis, CA's urban forest demonstrates that useful analyses can be applied to small cities at low costs. Researchers used stratified random sampling and supplemental data from a recent analysis of nearby Modesto, CA to conduct a thorough quantification of the structure and benefits of Davis's trees. They found that for each dollar invested, trees returned an average of \$3.78 in benefits from atmospheric CO_2 reductions and electricity and natural gas use decreases, among other savings—a \$52.43 annual net benefit per tree. Forty percent of annual benefits were attributed to environmental values while the remaining 60% resulted from increased property values. Researchers found that large, deciduous trees performed best for the city's uses and climate, followed by conifers, then broadleaf evergreens (see figure 5).

City-level urban forest structure analyses and catalogues allow managers to make informed decisions that will maximize benefits. As the above research has demonstrated, there is no one-size-fits-all plan for an urban forest. Costs and benefits vary greatly from city to city depending upon climate, species, population, pollutant levels, and planting patterns of trees. The more managers are able to understand where their greatest costs are coming from (high BVOCs emittors? pruning practices?) and what their greatest benefits are (property value? energy reduction?) the more informed their long term strategies could be. STRATUM and UFORE models also allow cities to assess possible threats to their urban forest which may not have been quantifiable before. For example, Bismarck's highly productive urban forest may be in danger, as 52% of public trees are *Ulmus Americana* and *Fraxinus pennsylvanica*, two species at particular risk due to Dutch Elm Disease (*Ophiostoma ulmi*) and the Emerald Ash Borer (*Agrilus planipennis Fairmaire*). A more stable street tree community could be achieved by introducing greater species diversity. Further, Berkeley's fairly low cost-benefit ratio was due primarily to high maintenance costs, suggesting that larger sidewalk cutouts and deeper rooting trees could help bring down maintenance outlays (McPherson et al., 2005).

These modeling tools are becoming increasingly accessible and ever easier to use. The USDA Forest Service, in cooperation with the Davey Resource Group (DRG), offers information and guidance online for UFORE and STRATUM at sites like the at www.ufore.org and www.itreetools.org. These programs are also available at no charge to communities nationwide. Nonprofit organizations like Casey Trees in Washington, DC lobby for increased public investment in tree planting through scientific assessments of the urban forest. The organization provides tools like an interactive map allowing residents to look up the value of particular street trees (see figure 6) and comprehensive guides to assist designers in healthy planting practices (see Tree Space Design Report: at http://www.caseytrees.org/planning/design-resources).

Simplified versions of the more complex computer models allow the layperson to conduct his or her own assessment of local trees or cities to conduct preliminary exploratory testing before launching full-scale analysis projects. Australia's Cooperative Research Centre for Greenhouse Accounting (CRC) offers an online calculator that only requires data input of tree circumference and type (hardwood vs. softwood) to make a generalized estimate of carbon storage (see: http://svc237.bne113v.server-web.com/index.cfm) (see figure 7). Casey Trees and DRG offer another useful online tool, the National Tree Benefits Calculator, which is based on the more intensive STRATUM model and powered by i-Tree (see: http://www.treebenefits.com/calculator/). This calculator, intended to be simple and accessible, requires input of location, species, diameter at breast height (DBH), and surrounding land use to return a total dollar value of a particular tree and a breakdown of values based on runoff reduction, property value, energy savings, carbon storage and avoidance, and air quality improvement (see figure 8 & 9). The authors acknowledge that such a simplified model can only serve as a starting place from which to understand the value of urban forest trees and directs you to the i-Tree website for more information on STRATUM and UFORE.

Somerville Street Tree Case Study

During his third inaugural address in January 2008, Somerville's Mayor Joseph Curtatone proposed a new initiative to increase the city's tree canopy by 20% over the following four years (15 May 2009, interview with Brad Arndt, Urban Forest Initiative Coordinator). The city understood that in order to undertake such an ambitious project they would first need to assess the current structure of the existing urban forest and the Somerville Urban Forest Initiative was born (see figure 10). From mid-May to mid-June 2009 consultant arborists from DRG will conduct a citywide data collection campaign. The collected information will be input and analyzed by the STRATUM and UFORE modeling tools in an attempt to fully assess the structure and value of Somerville's public trees and to assist with long-term planting and management strategies ("Somerville Urban Forest Initiative," 2009).

Somerville, which has been named a "Tree City USA" for the past 13 years by the National Arbor Day Foundation, has roughly 10,000 trees in the public right of way. The most prevalent street trees include *Acer platanoides, Acer rubrum, Quercus palustris, Zelkova serrata,* and *Pyrus calleryana*. Some of the city's oaks and pines tower to over 80 feet tall. The city pays for the installation and maintenance of its trees through Department of Public Works (DPW) funds and Community Development Block Grant (CDBG) money awarded by the U.S. Department of Housing and Urban Development. Roughly 150 new trees are planted annually, 100 through the CDBG budget and the remaining 50 using DPW funds. The city spends $3.17 per capita on urban and community forestry expenditures (Arndt).

The field study component of this paper attempts to apply a simple assessment tool to analyze a small sample of street trees in Somerville for their value to the city. This investigation is particularly relevant due to the current focus on Somerville's urban forest and will be interesting to compare with more comprehensive and accurate measures conducted by the city and its consulting arborists.

Two 500-meter sections of street trees (including both the east and west sides of the streets) in southern Somerville were sampled: along lower Beacon Street and along the Perry Street/Wyatt Street corridor slightly to the east. Figure 11 shows the area of analysis; figures 12-15 are images taken during the sampling process. Beacon Street is a high volume, relatively high-speed thoroughfare while Perry and Wyatt Streets are lower speed, quieter roadways. Both sampled corridors allow for two-way traffic and street parking and multi-family housing is the primary land use along both streets. Lincoln Park borders the northwestern edge of the Perry Street sample area.

Location, species, and DBH were recorded for each of the 91 trees along the sampled street corridors, comprised of 51 along Beacon Street and 40 along Perry and Wyatt Streets. Twelve different species of trees were recorded (see the appendix, table 1 for a full list of species), the most prevalent being *Pyrus calleryana* at 38.5% of the total sample, followed by *Quercus palustris*, *Acer platanoides*, and *Fraxinus pennsylvanica*, at 11%, 10% and 10%, respectively. Tree sizes ranged from 2.5 inches in diameter to a 24-inch pin oak growing along the edge of Lincoln Park.

The samples were analyzed using the public estimation tool described in the previous section, the National Tree Benefits Calculator. An attempt was made to analyze the samples using the UFORE modeling system (software generously provided by the city of Somerville) but a lack of data acquisition tools to accurately measure attributes (ex. crown size and tree height) and the difficulty obtaining data from outside sources (ex. land cover imagery, meteorological data) meant the attempt yielded little of use. Instead, the Tree Benefits Calculator was used to determine total tree value, stormwater interception value, electricity use reduction, air quality improvement, property value increased, natural gas use reduction (all in dollars per year), gallons of stormwater intercepted, and pounds of carbon sequestered and avoided (see the appendix for a full spreadsheet of these results).

The total estimated annual value of all street trees sampled was $7,429, with an average benefit of $81.63 per tree per year (see figure 16). The total amount of water captured by the entire sample of street trees was 74,496 gallons per year (at an average of 819 gallons per tree), with an estimated total benefit of $588.75. Additionally, the trees reduced atmospheric carbon by a total of an estimated 24,354 pounds per year. Although Beacon Street had 11 more trees included in the survey, the sample value total ($3,289) was less than the total value for the Perry/Wyatt Street sample ($4,140). This difference was due primarily to discrepancies in the size and age of the populations. The Beacon Street sample, with an average value of $64.50 per tree per year, had an average diameter of seven inches, while the Perry/Wyatt trees had an average value of $103.50/year and an average diameter of 10.9 inches. Total estimated values ranged greatly depending on DBH. Trees with diameters between two and six inches had an average value of $38.79 per year while trees with diameters between 18 and 24 inches had an average value of $166.14 per year (see figure 17).

Carbon sequestration capabilities, greatly affected by the maturity of the tree, varied drastically between samples, the Beacon Street trees averaging 80.2 lbs. of carbon sequestered per year compared to the 187.2 lbs/year held by the Perry/Wyatt trees.

Property value increases made up the highest percentage (46%) of the total benefits of all trees sampled (see figure 18). Thirty percent of total benefits were due to estimated reductions in natural gas use while reductions in electricity use, decreased stormwater runoff, and air quality improvements accounted for 8%, 8%, and 7% of the total, respectively. Reductions in atmospheric carbon due to sequestration and avoidance made up only 1% of the total estimated tree values.

Although the sample size was small and tree diameters varied greatly between species, an attempt was made to ascertain which tree types were providing the most value for the city of Somerville. Averaging values per tree by species showed that the *Gleditsia triancanthos var. inermis*, *Quercus palustris*, and *Zelkova serrata* had the highest average estimated value, $200, $155.30, and $106.50, respectively, while the *Prunus sp.* had the lowest at $37.33 (see figure 19). In an attempt to control for variations in tree size, an average dollar value per inch in diameter was also calculated (average species value divided by average species DBH). Based on this calculation, the species with the highest estimated values for Somerville were *Zelkova serrata* ($16.64 per DBH inch), *Acer rubrum*

($12.00 per DBH inch), and *Pyrus calleryana* ($11.66 per DBH inch) (see figure 20). The least beneficial tree species were *Prunus sp*. ($4.91 per DBH inch) and *Acer platanoides* ($7.04 per DBH inch).

There are a variety of very great error potentials and restrictions on the results and analysis described above. The use of the Tree Benefits Calculator as a data generator guarantees many assumptions and generalizations that are not tolerated in more thorough and specific cataloguing and analysis using the full STRATUM or UFORE models. The makers of the Calculator underscore that its use is for estimation purposed only. Not including tree height, crown size, aerial imaging, and more specific environmental, pollutant, and cost data for the city makes for a very large margin of error. Additionally, the small sample size and collection error probably also contribute to inaccuracies.

Nonetheless, even a flawed attempt to quantify the structure and value of a small sample of the city's street trees is a useful exercise. Such a case study demonstrates how much constructive information could be generated from a more accurate and thorough understanding of Somerville's urban forest. Data could be used to direct plant selection based on ensuring species variety, maximizing benefits like property value, while minimizing costs, such as BVOC emissions. Design decisions could be made based on strategies to shade structures to reduce energy costs or shade parking and road surfaces to reduce air temperature. Further, the wealth of information gleaned from current models of urban forest analysis recommends potential studies incorporating other benefits of the urban forest like quality of life improvements, public health savings, and vital ecological functions. The more we understand about our urban forests and their needs and potentials, the better equipped we are to manage them effectively and assist our "green infrastructures" in reaching their fullest potential.

Figures

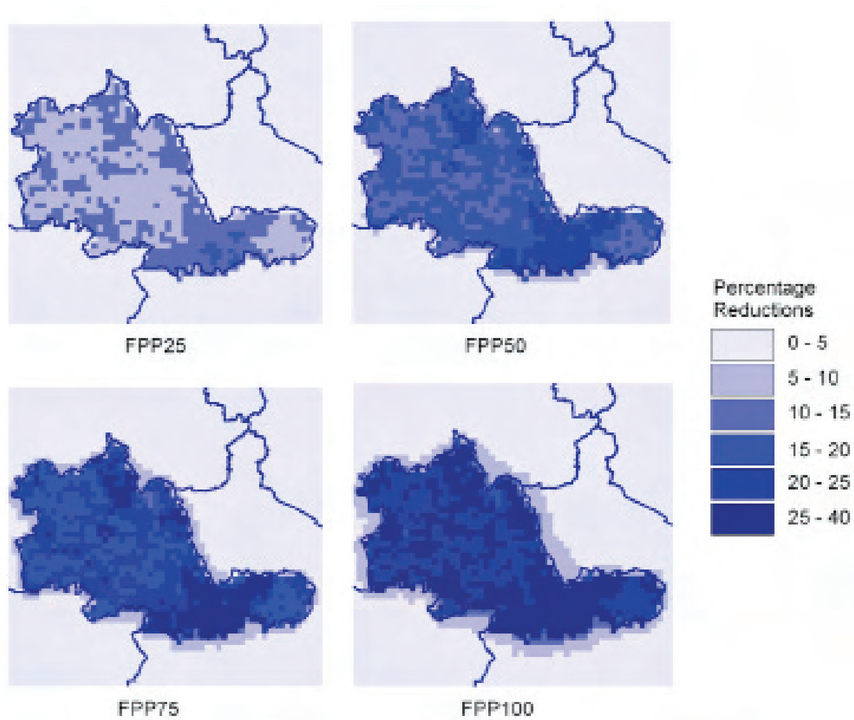


Figure 1: “West Midlands primary PM10 percentage concentration reductions.” (FPP: future planting potential with percentage of potential estimated). (source: McDonald et al., 2007)

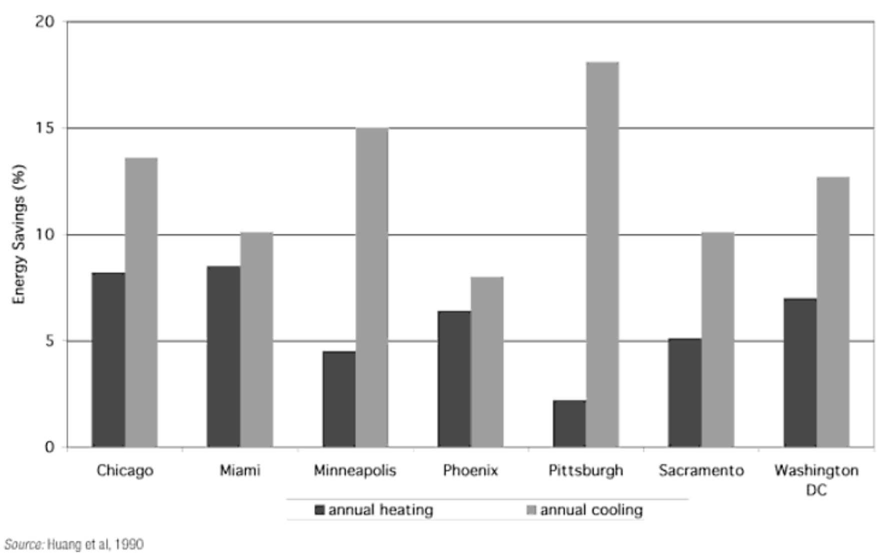


Figure 2: “Predicted energy savings in typical homes in seven US cities due to tree shading and wind shielding effects, assuming one tree is planted to the south and one to the west.” (source: Gartland, 2008)

City	Number of trees		Tree density		Tree cover (%)	
	Total	SE	Mean	SE	Mean	SE
Atlanta, GA	9,420,000	749,000	276	22	32.9	na
New York, NY	5,220,000	719,000	65	9	16.6	0.3
Chicago, IL	4,130,000	634,000	68	10	11.0	0.2
Baltimore, MD	2,600,000	406,000	109	17	18.9	na
Philadelphia, PA	2,110,000	211,000	62	6	21.6	0.4
Oakland, CA	1,590,000	51,000	120	4	21.0	0.2
Boston, MA	1,180,000	109,000	83	8	21.2	0.4

na = not analyzed; base data for Atlanta from American Forests; base data for Baltimore from Grove (1996).

Figure 3: “Estimates of number of trees and tree density (trees per hectare) for cities analyzed with the UFORE model. (source: Nowak & Crane, 2000).

Pollutant	New York, NY Removal	New York, NY Value	Atlanta, GA Removal	Atlanta, GA Value	Baltimore, MD Removal	Baltimore, MD Value
O_3	506 (124-631)	3,417 (839-4,263)	514[1] (101-604)	3,471[1] (684-4,081)	180 (42-221)	1,214 (284-1,494)
PM10[2]	470 (182-834)	2,120 (819-3,761)	406 (157-706)	1,833 (709-3,184)	137 (53-239)	618 (239-1,079)
NO_2	510 (216-593)	3,441 (1,459-4,004)	145 (72-165)	979 (483-1,115)	115 (48-134)	733 (322-907)
SO_2	238 (117-358)	394 (193-593)	95 (42-137)	158 (69-227)	55 (25-85)	91 (42-140)
CO	97	93	35	33	13	12
Total	1,7821 (736-2,514)	9,465 (3,404-12,713)	1,196 (407-1,648)	6,474 (1,979-8,640)	499 (181-692)	2,709 (900-3,632)

[1] Average national O_3 monthly trend data were used to estimate missing data for January, February, and December.
[2] Assumes 50 percent resuspension of particles.

Figure 4: "Total estimated pollution removal (metric tons) by trees during nonprecipitation periods (dry deposition and associated monetary value." (source: Nowak & Crane, 2000).

Species	DBH class (cm [in]) 0-7.5 (0-3)	7.6-15.1 (3-6)	15.2-30.4 (6-12)	30.5-45.6 (12-18)	45.7-60.9 (18-24)	61.0-76.2 (24-30)	>76.2 (>30)	Total Avg.
Lg. Deciduous	26.55	78.22	124.70	125.48	104.96	98.57	113.28	98.05
Med. Deciduous	21.68	52.81	81.66	87.32	104.29	81.26	93.41	70.00
Sm. Deciduous	9.07	16.82	14.84	17.76	20.67	NP	NP	12.96
Lg. Broadleaf Evergreen	7.04	22.12	49.53	97.48	123.89	116.28	109.92	54.42
Med. Broadleaf Evergreen	10.55	27.38	51.98	75.83	69.02	107.31	NP	29.90
Sm. Broadleaf Evergreen	13.68	28.82	41.08	41.08	41.08	NP	41.08	30.59
Lg. Conifer	16.81	48.14	82.69	77.36	79.70	96.48	104.81	70.61
Med. Conifer	NP	NP	NP	NP	NP	NP	NP	NP
Sm. Conifer	9.37	NP	NP	NP	9.75	NP	NP	9.59
All public trees	18.28	49.17	92.47	92.20	101.42	97.18	111.65	71.12

Figure 5: "Average (weighted annual benefits ($) produced by tree types as a function of DBH class (NP= no public trees present in age class)." (source: Maco & McPherson, 2003).

Figure 6: Casey Trees Washington, DC street tree inventory viewing tool. (source: www.caseytrees.org)

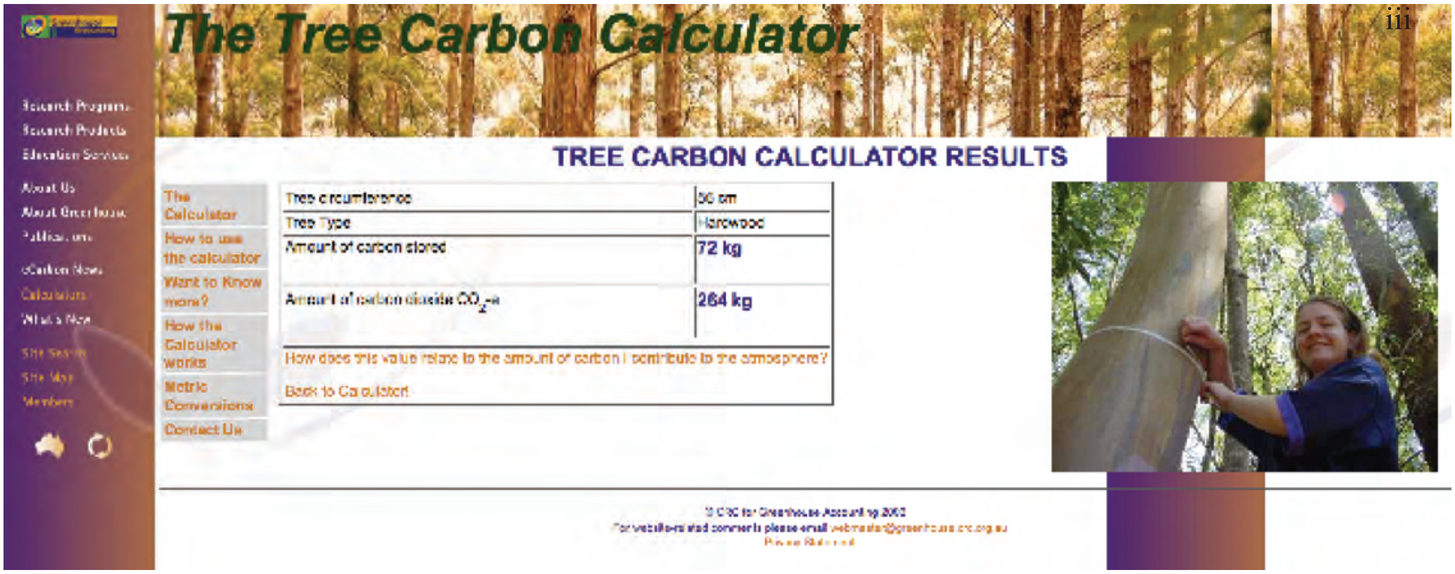
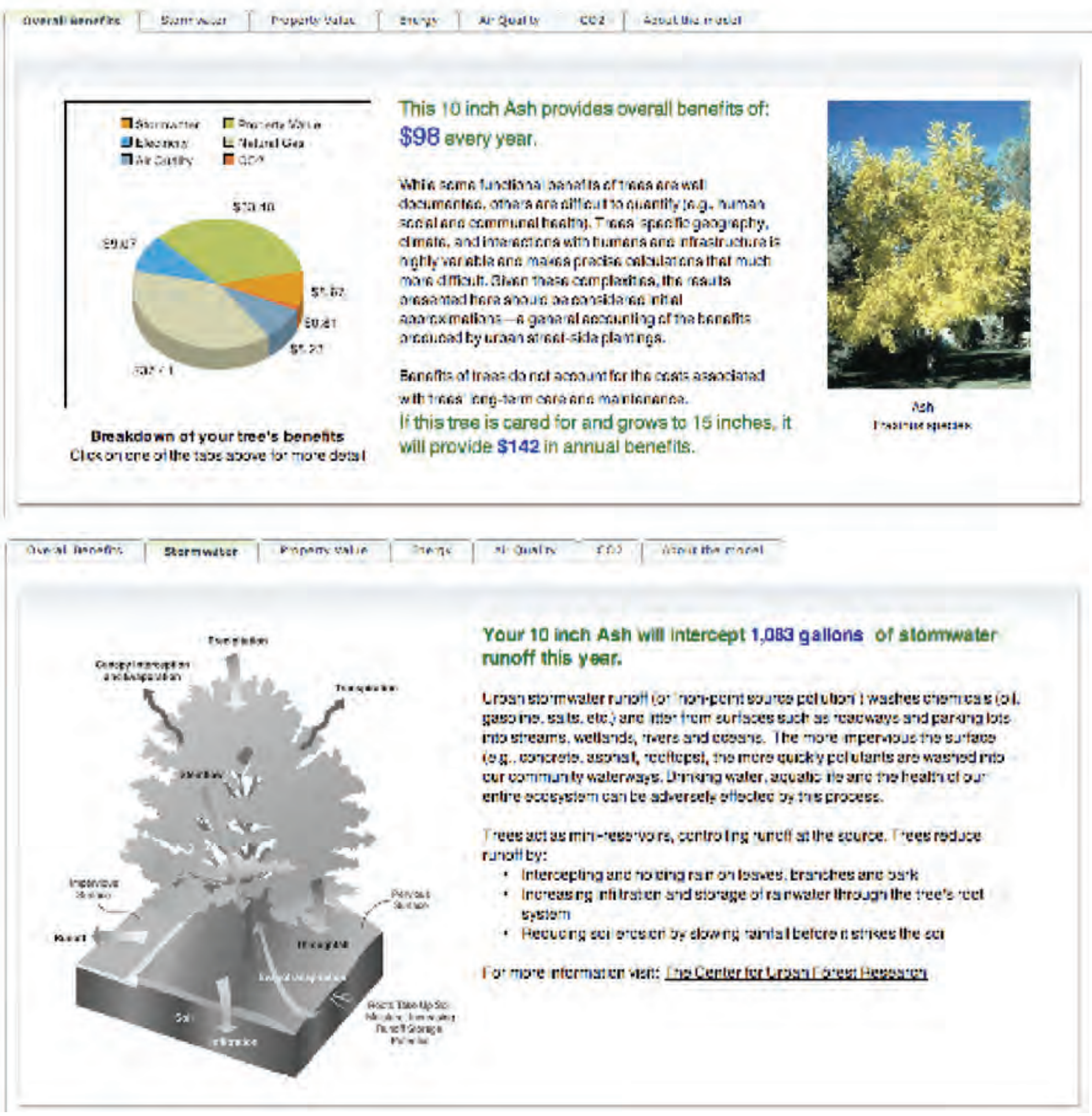


Figure 7: CRC's online tree carbon calculator. (source: http://svc237.bne113v.server-web.com/calculators/treecarbon.htm#start)



Figures 8 & 9: National Tree Benefits Calculator results pages for overall tree value and stormwater interception. (source: www.treebenefits.com/calculator)

Figure 10: Brad Arndt, Urban Forest Initiative Coordinator, City of Somerville, at the city's Living Green Festival. (image date: 16 May 2009)

Figure 11: please see the following page

Figure 12: (below) Data collection along Beacon Street. (image date: 15 May 2009)

Figure 13: (right) *Quercus palustris* (pin oak) trees growing in Lincoln Park to the east of Perry Street. (image date: 15 May 2009)

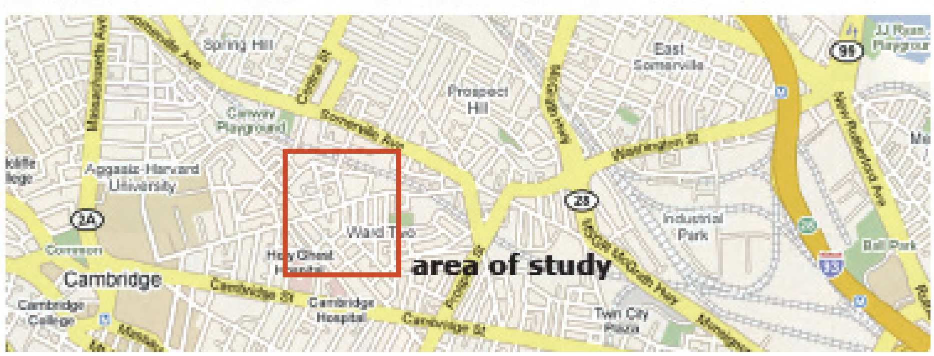


Figure 11: Map of the two street sections from which sample data was collected, Beacon Street and Perry/Wyatt Streets.

Figure 14: (left) A *Fraxinus pennsylvanica* (green ash) pruned so as to not disrupt overhead wires, along the west side of Beacon Street. (image date: 15 May 2009)

Figure 15: (right) City notice regarding tree work along Perry Street. (image date: 15 May 2009)

	total value	stormwater inter.	electricity	air quality	prop. value	natural gas	CO2	storm water	CO2 sequest.	CP2 avoided	CO2 total
	$/yr	$/yr	$/yr	$/yr	$/yr	$/yr	$/yr	gal./yr.	lbs./yr.	lbs./yr.	lbs./yr.
BEACON ST TOTALS	3289	232.33	244.36	245.29	1585.1	977.28	28.88	30030	4092	5369	9461
PERRY/WYATT ST TOTALS	4140	356.42	340.75	306.79	1817.8	1267.39	43.34	44466	7488	7405	14893
SUMM. TOTALS	**7429**	**588.75**	**585.13**	**552.08**	**3402.9**	**2244.67**	**72.22**	**74496**	**11580**	**12774**	**24354**
AVERAGE PER TREE	**$81.63**	**$6.47**	**$6.43**	**$6.07**	**$37.39**	**$24.67**	**$0.79**	**818.64**	**127.25**	**140.37**	**267.63**

Figure 16: Results summary table including total value and other benefits for both sample streets.

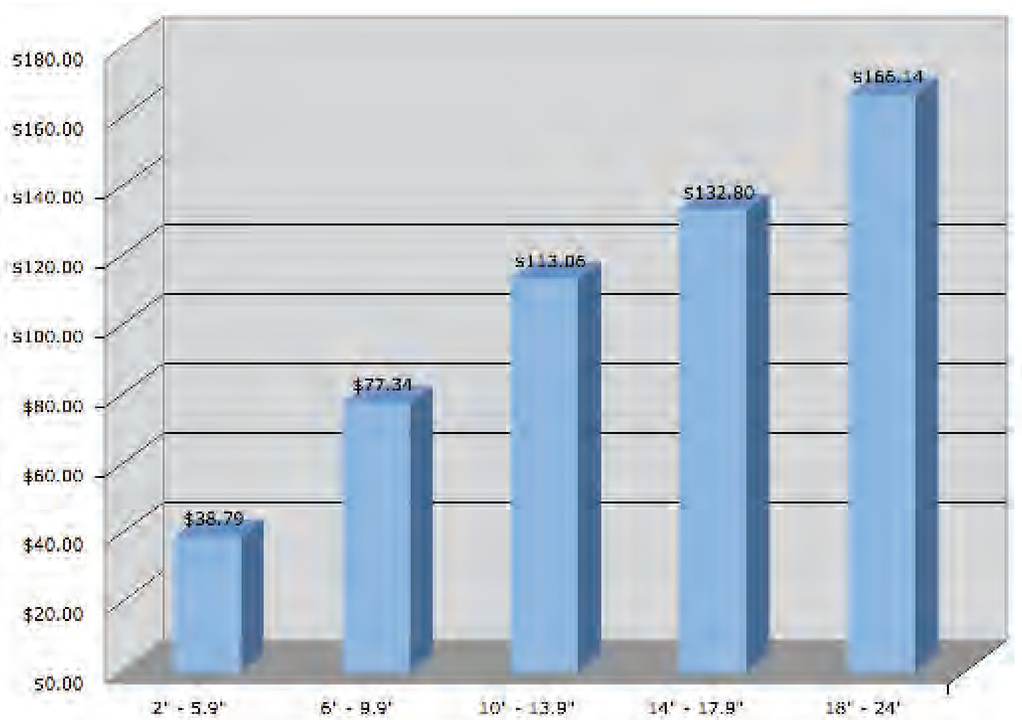


Figure 17: Average estimated total tree benefits by tree size (DBH). Results shown in dollars per year.

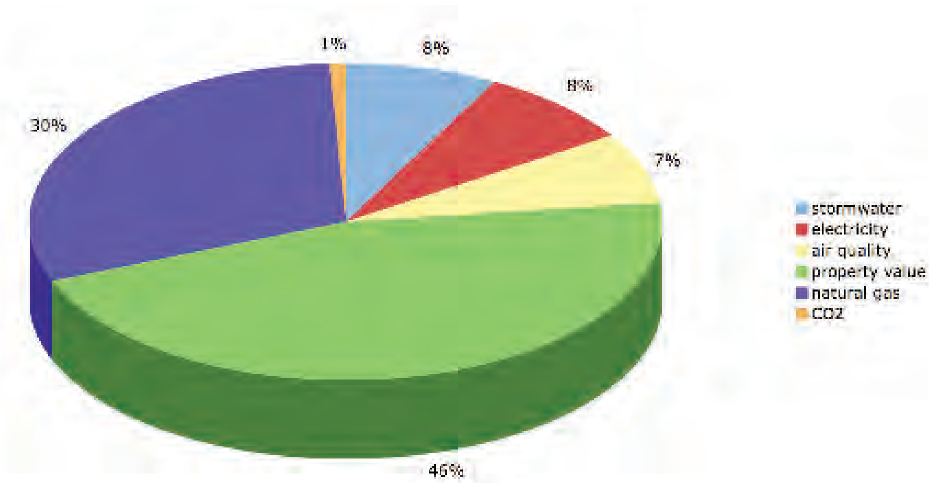
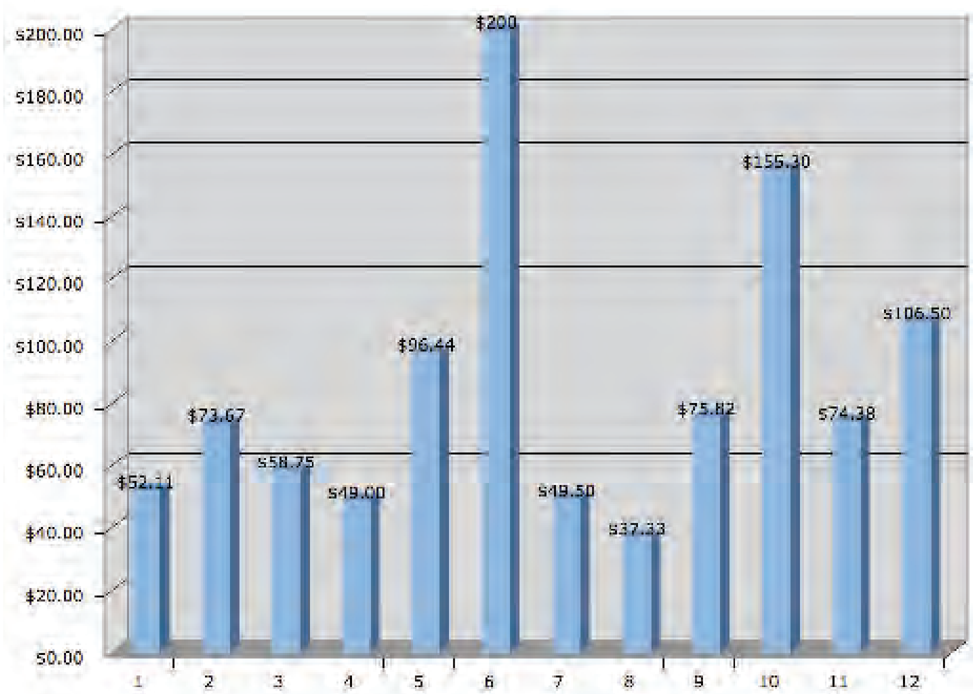


Figure 18: Breakdown by value source for total benefits ($7.429/ year) for all street trees sampled



1 - *Acer platanoides*
2 - *Acer platanoides 'Crimson King'*
3 - *Acer rubrum*
4 - *Acer saccharum*
5 - *Fraxinus pennsylvanica*
6 - *Gleditsia triacanthos var. inermis*
7 - *Platanus x acerifolia*
8 - *Prunus sp.*
9 - *Pyrus calleryana*
10 - *Quercus palustris*
11 - *Tilia cordata*
12 - *Zelkova serrata*

Figure 19: Average total value per tree by species.

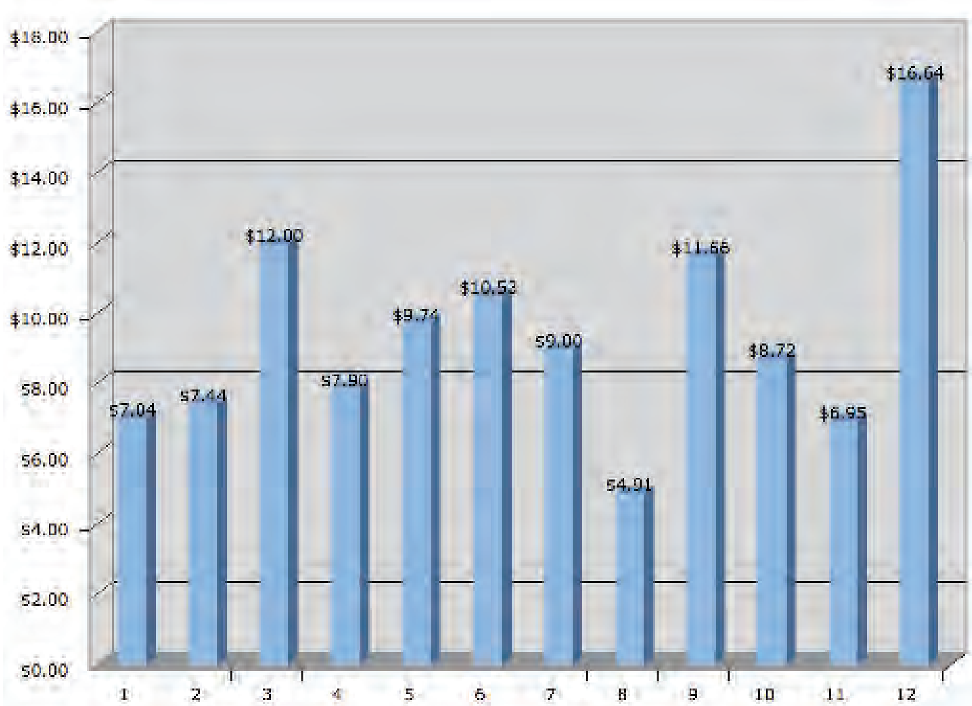


Figure 20: Average total value by inch in diameter by species (average benefit divided by average DBH for each species).

Appendix

Table 1: Trees Sampled

Species code	Species name	Common name	Total sampled	Percentage of survey
1	*Acer platanoides*	Norway maple	9	10%
2	*Acer platanoides* 'Crimson King'	Crimson King maple	3	3.3%
3	*Acer rubrum*	red maple	4	4.4%
4	*Acer saccharum*	sugar maple	4	4.4%
5	*Fraxinus pennsylvanica*	green ash	9	10%
6	*Gleditsia triacanthos var. inermis*	thornless honeylocust	1	1%
7	*Platanus x acerifolia*	London planetree	2	2.2%
8	*Prunus sp.*	flowering cherry	6	6.6%
9	*Pyrus calleryana*	Callery pear	35	38.5%
10	*Quercus palustris*	pin oak	10	11%
11	*Tilia cordata*	littleleaf linden	8	8.8%
12	*Zelkova serrata*	Japanese zelkova	2	2.2%
		total	91	

Table 2: Data spreadsheet information

Tree codes:
BW#: Beacon Street, west side
BE#: Beacon Street, east side
PW#: Perry/Wyatt Streets, west side
PE#: Perry/Wyatt Streets, east side

species code: see table 1
DBH: diameter at breast height (measured at 4.5 feet above the ground)

Data Label	Units	notes
"Total value"	Dollars/year	
"Stormwater inter."	Dollars/year	Value of stormwater intercepted by tree
"Electricity"	Dollars/year	Value of reduced energy use
"Air quality"	Dollars/year	
"Property value"	Dollars	Increase in property value due to tree's presence, calculated for multifamily housing types
"Natural gas"	Dollars/year	Value of reduced natural gas use
"CO2"	Dollars/year	Value of CO_2 sequestration and avoidance due to reduced energy needs
"Stormwater gal."	Gallons/year	Gallons of rainwater intercepted
"CO2 reduction: sequest."	Pounds/year	Reduced atmospheric carbon due to sequestration
"CO2 reduction: avoided"	Pounds/year	Reduced atmospheric carbon due to reduced energy needs
"CO2 reduction: total"	Pounds/year	Total reduced atmospheric carbon

(source: http://www.treebenefits.com/calculator)

Sampling Data Tables

tree code	sp. code	circ.	DBH	total value	stormwater inter.	electricity	air quality	prop. value	natural gas	CO2	storm water	CO2 sequest.	CO2 avoided	CO2 total
unit		*in.*	*in.*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*gal./yr.*	*lbs./yr.*	*lbs./yr.*	*lbs./yr.*
BW1	3	8.5	2.7	44	1.36	0.93	0.86	36.29	4.77	0.13	170	22	20	42
BW2	1	17	5.4	34	2.26	2.72	2.62	12.84	13.32	0.33	283	54	58	112
BW3	1	13	4.1	24	1.44	1.72	1.66	9.93	8.84	0.21	180	34	37	71
BW4	1	16.5	5.3	33	2.19	2.64	2.54	12.6	12.95	0.32	274	51	58	109
BW5	1	12	3.8	22	1.3	1.54	1.49	9.33	7.94	0.19	163	31	33	64
BW6	1	19.5	6.2	41	2.83	3.4	3.27	14.71	16.23	0.41	354	65	76	141
BW7	5	43	13.7	131	12.94	14.52	37.36	37.36	52.07	1.29	1618	110	322	432
BW8	5	46	14.6	139	13.98	15.84	13.66	38.33	55.64	1.4	1748	130	342	472
BW9	5	33.5	10.7	104	9.47	10.1	9.06	34.15	40.19	0.9	1184	78	219	297
BW10	5	26	8.3	82	6.8	6.83	6.34	31.59	30.22	0.61	850	50	148	198
BW11	11	35	11.1	79	6.72	7.64	6.26	28.64	29.04	0.85	841	123	170	293
BW12	11	24	7.6	58	3.94	3.82	3.28	30.1	16.5	0.57	492	90	81	171
BW13	11	24	7.6	58	3.94	3.82	3.28	30.1	16.5	0.57	492	90	81	171
BW14	11	20.75	6.6	52	3.24	3.07	2.6	30.13	12.85	0.43	405	74	68	142
BW15	11	23.5	7.5	58	3.94	3.82	3.28	30.1	16.5	0.57	492	90	81	171
BW16	11	35	11.1	79	6.72	7.64	6.26	28.64	29.04	0.85	841	123	170	293
BW17	11	38.75	12.3	86	7.76	9.22	7.41	27.83	33.29	0.97	970	140	199	339
BW18	9	10	3.2	35	1.2	1.05	1.03	27.04	4.47	0.2	150	37	23	60
BW19	9	10	3.2	35	1.2	1.05	1.03	27.04	4.47	0.2	150	37	23	60
BW20	5	24	7.6	76	6.1	6.06	5.62	30.86	26.99	0.54	762	40	136	176
BW21	5	32.25	10.3	100	9.01	9.51	8.59	33.72	38.6	0.85	1127	70	209	279
BW22	9	14.5	4.6	48	1.99	1.79	1.75	35.15	7.32	0.33	249	60	42	102
BW23	9	8.25	2.6	29	0.89	0.75	0.75	23.6	3.33	0.14	1011	25	18	43
BW24	9	12.5	4	42	1.62	1.45	1.42	31.62	6	0.27	203	52	31	83
BW25	9	13.5	4.3	45	1.78	1.6	1.56	33.33	6.57	0.3	223	56	36	92
BW26	9	12.5	3.9	41	1.57	1.4	1.37	31.04	5.81	0.26	196	50	31	81
BW27	9	11.75	3.7	40	1.47	1.3	1.27	29.9	5.43	0.24	183	46	29	75
BW28	9	11.75	3.7	40	1.47	1.3	1.27	29.9	5.43	0.24	183	46	29	75
BW29	9	13	4.1	43	1.68	1.5	1.46	32.19	6.19	0.28	210	52	34	86

tree code	sp. code	circ.	DBH	total value	stormwater inter.	electricity	air quality	prop. value	natural gas	CO2	storm water	CO2 sequest.	CO2 avoided	CO2 total
unit		*in.*	*in.*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*gal./yr.*	*lbs./yr.*	*lbs./yr.*	*lbs./yr.*
BW30	9	12.25	3.9	41	1.57	1.4	1.37	31.04	5.81	0.26	196	50	31	81
BW31	9	11	3.5	38	1.36	1.2	1.18	28.75	5.04	0.22	170	41	28	69
BW32	9	30.5	9.7	118	7.6	7.14	6.94	68.55	26.67	1.09	950	180	152	332
BW33	9	23	7.3	84	4.73	4.27	4.26	53.18	17.34	0.7	591	120	73	193
BW34	9	24	7.6	89	5.04	4.54	4.54	55.19	18.45	0.74	629	120	108	228
BE1	3	38	12.1	105	10.94	10.22	8.75	35.22	39.03	0.96	1367	105	228	333
BE2	1	40	12.7	100	8.32	10.56	9.25	32.01	38.87	1.24	1040	205	236	441
BE3	1	47	15	122	10.49	13.54	11.56	38.68	46.62	1.58	1311	260	305	565
BE4	5	30	9.6	94	8.2	8.48	7.76	32.97	35.83	0.76	1025	62	186	248
BE5	5	19.5	6.2	64	4.68	4.52	4.19	29.39	20.53	0.4	585	30	101	131
BE6	5	24.5	7.8	78	6.3	6.28	5.83	31.07	27.91	0.56	787	45	137	182
BE7	1	17	5.4	34	2.26	2.72	2.62	12.84	13.32	0.33	283	54	58	112
BE8	9	34	10.8	135	9.4	9.19	8.65	74.84	31.42	1.34	1175	200	209	409
BE9	9	30	9.6	116	7.44	6.95	6.78	61.97	26.24	1.06	930	170	155	325
BE10	4	16.5	5.3	42	2.97	2.9	2.65	19.91	13.64	0.33	371	46	65	111
BE11	4	22	7	56	4.44	4.35	3.98	23.11	20.1	0.48	555	70	94	164
BE12	9	8	2.5	29	0.83	0.7	0.7	23.03	3.14	0.13	104	25	15	40
BE13	9	8	2.5	29	0.83	0.7	0.7	23.03	3.14	0.13	104	25	15	40
BE14	9	9.5	3	33	1.1	0.95	0.94	25.89	4.09	0.18	137	33	21	54
BE15	9	10.5	3.3	36	1.26	1.1	1.08	27.61	4.66	0.21	157	40	23	63
BE16	2	39.25	12.5	98	8.13	10.3	9.05	31.43	38.2	1.21	1017	200	230	430
BE17	2	23	7.3	50	3.63	4.34	4.16	17.29	20.73	0.52	542	85	95	180
			TOTAL	**3289**	**232.33**	**244.38**	**245.29**	**1585.1**	**977.28**	**28.88**	**30030**	**4092**	**5369**	**9461**

tree code	sp. code	circ.	DBH	total value	stormwater inter.	electricity	air quality	prop. value	natural gas	CO_2	storm water	CO_2 sequest.	CO_2 avoided	CO_2 total
unit		*in.*	*in.*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*gal./yr.*	*lbs./yr.*	*lbs./yr.*	*lbs./yr.*
PW1	2	31	9.9	73	5.68	6.94	6.44	23.89	29.45	0.83	710	140	149	289
PW2	6	59	19	200	22.99	22.93	20.15	52.93	79.55	1.91	2874	200	510	710
PW3	8	20	6	31	2.16	2.84	2.78	8.18	14.24	0.35	271	60	60	120
PW4	8	25.5	8	39	2.97	3.79	3.72	9.1	18.92	0.49	371	90	82	172
PW5	8	19	6	31	2.16	2.84	2.78	8.18	14.24	0.35	271	60	60	120
PW6	8	25	8	39	2.97	3.79	3.72	9.1	18.92	0.49	371	90	82	172
PW7	9	18.25	5.8	64	3.21	2.89	2.87	43.16	11.77	0.5	401	87	64	151
PW8	9	24.5	7.8	91	5.24	4.73	4.73	56.52	19.2	0.76	655	130	103	233
PW9	9	22	7	80	4.43	3.99	3.98	51.18	16.23	0.66	553	117	84	201
PW10	7	18.5	5.9	54	3.85	4.02	3.32	24.93	17.18	0.36	481	30	88	118
PW11	7	16	5	45	3	3.03	2.48	23.58	12.94	0.28	375	22	67	89
PW12	9	28.5	9.1	109	6.62	6.01	6	65.11	24.08	0.95	828	160	130	290
PW13	9	27	8.6	102	6.05	5.46	5.48	61.87	22.16	0.87	756	147	119	266
PW14	9	31	9.9	121	7.93	7.51	7.25	69.69	27.53	1.13	991	180	166	346
PW15	9	28	8.9	106	6.36	5.74	5.75	63.87	23.28	0.91	794	156	123	279
PE1	11	68	21.6	125	16.03	15.78	14.12	16.62	61.07	1.17	2004	150	259	409
PE2	3	7.5	2.4	43	1.08	0.75	0.69	36.3	3.06	0.11	135	18	17	35
PE3	3	8	2.5	43	1.08	0.75	0.69	36.3	3.06	0.11	135	18	17	35
PE4	12	19	6	102	4.4	7.58	5.78	49.83	33.64	0.7	549	50	168	218
PE5	12	21.5	6.8	111	5.27	3.59	6.67	52.57	37.1	0.8	659	60	192	252
PE6	10	62	19.7	171	20.08	17.39	15.01	57.58	59.26	2.13	2510	440	375	815
PE7	10	64.5	20.5	178	21.23	17.91	15.68	59.07	61.28	2.21	2654	471	382	853
PE8	10	65	20.7	180	21.57	18.04	15.85	59.45	62.66	2.23	2690	480	383	863
PE9	10	75.25	24	209	27.07	21.7	19.4	65.26	72.84	3.05	3384	600	459	1059
PE10	10	46	14.6	129	12.89	13.73	10.62	47.96	41.92	1.62	1611	275	295	570
PE11	10	72	23	100	9.17	9.03	7.28	42.19	30.99	1.11	1146	186	200	386
PE12	10	35.5	11.3	200	25.36	20.54	18.3	63.52	69.79	2.79	3171	550	449	999
PE13	10	51.25	16.3	143	15.21	15.2	12.13	51.12	47.68	1.8	1901	327	327	654
PE14	10	40	12.7	112	10.75	11.05	8.7	44.64	35.63	1.33	1343	227	237	464
PE15	10	46.5	14.8	131	13.12	14.07	10.33	48.31	43.58	1.65	1640	273	308	581
PE16	9	30	9.6	116	7.44	6.95	6.78	67.97	26.24	1.06	930	171	154	325
PE17	9	26	8.3	98	5.75	5.19	5.2	59.86	21.05	0.83	718	144	110	254

Beacon Street and Perry/Wyatt Street Analyses
500 meter sample

Somerville, MA
data collected: 15 May 2009

tree code	sp. code	circ.	DBH	total value	stormwater inter.	electricity	air quality	prop. value	natural gas	CO2	storm water	CO2 sequest.	CO2 avoided	
unit		*in.*	*in.*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*gal./yr.*	*lbs./yr.*	*lbs./yr.*	
PE18	8	31.5	10	47	3.79	4.84	4.64	10.04	22.92	0.64	474	127	106	233
PE19	9	30.5	9.7	118	7.6	7.14	6.94	68.55	26.67	1.09	950	180	152	332
PE20	8	23.5	7.5	37	2.77	3.55	3.49	8.87	17.75	0.45	366	182	77	259
PE21	9	19.5	6.2	70	3.61	3.26	3.24	45.83	13.26	0.55	452	95	73	168
PE22	9	36	11.5	146	10.54	10.5	9.74	78.85	34.44	1.5	1218	235	223	458
PE23	1	26.5	8.4	59	4.4	5.27	5.05	19.87	24.23	0.64	550	102	117	219
PE24	9	33.5	12.3	158	11.85	11.99	10.98	83.43	37.89	1.68	1481	258	257	515
PE25	9	32.5	10.4	129	8.74	8.44	8.03	72.55	29.69	1.25	1093	200	181	381
			TOTAL	**4140**	**356.42**	**340.75**	**306.79**	**1817.8**	**1267.39**	**43.34**	**44466**	**7488**	**7405**	**14893**

	total value	stormwater inter.	electricity	air quality	prop. value	natural gas	CO2	storm water	CO2 sequest.	CO2 avoided	CO2 total
	$/yr	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*$/yr*	*gal./yr.*	*lbs./yr.*	*lbs./yr.*	*lbs./yr.*
BEACON St TOTALS	3289	232.33	244.38	245.29	1585.1	977.28	28.88	30030	4092	5369	9461
PERRY/WYATT St TOTALS	4140	356.42	340.75	306.79	1817.8	1267.39	43.34	44466	7488	7405	14893
SUMM. TOTALS	**7429**	**588.75**	**585.13**	**552.08**	**3402.9**	**2244.67**	**72.22**	**74496**	**11580**	**12774**	**24354**
AVERAGE PER TREE	**$81.63**	**$6.47**	**$6.43**	**$6.07**	**$37.39**	**$24.67**	**$0.79**	**818.64**	**127.25**	**140.37**	**267.63**

References

Beckett, K., Freer-Smith, P., & Taylor, G. (2000, December). Particulate pollution capture by urban trees: effect of species and windspeed. Global Change Biology, 6(8), 995-1003.

Casey Trees (2008). “Tree Inventory” & “Planning and Design.” <http://www.caseytrees.org>. Cited 17 May 2009.

Casey Trees and Davey Tree Experts Co. (2006). “National Tree Benefits Calculator.” <http://www.treebenefits.com/calculator/>. Cited 12 May 2009.

City of Somerville (2009). “Tree Inventory Fact Sheet.”

City of Somerville (2009). Draft Open Space and Recreation Plan, 2008-2013.

Cooperative Research Centre for Greenhouse Accounting (2003). “Tree Carbon Calculator.” <http://svc237.bne113v.server-web.com/calculators/treecarbon.htm#start>. Cited 14 May 2009.

Escobedo, F., & Nowak, D. (2009, April 30). Spatial heterogeneity and air pollution removal by an urban forest. Landscape & Urban Planning, 90(3/4), 102-110.

Gartland, L. (2008). Heat Islands: understanding and mitigating heat in urban areas. London: Earthscan.

Nowak, D.J. (1994). Air Pollution Removal by Chicago’s Urban Forest. USDA Forest Service General Technical Report, NE186, 63-79.

Nowak, D.J., and D.E. Crane. (2000). The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions. In: Hansen, M. and T. Burk (Eds.) Integrated Tools for Natural Resources Inventories in the 21st Century. Proc. Of the IUFRO Conference. USDA Forest Service General Technical Report NC-212. North Central Research Station, St. Paul, MN. pp. 714-720.

Nowak, D., Rowntree, R. A., McPherson, E. G., Sisinni, S. M., Kerkmann, E. R., Stevens., J. C. (1996, April). Measuring and analyzing urban tree cover. Landscape and Urban Planning, 36, 49-57.

Maco, S. E. & McPherson, E. G. (2003, March). A practical approach to assessing structure, function, and value of street tree populations in small communities. Journal of Arboriculture, 29(2): 84-97.

McDonald, A., Bealey, W., Fowler, D., Dragosits, U., Skiba, U., Smith, R., et al. (2007, December 11). Quantifying the effect of urban tree planting on concentrations and depositions of PM10 in two UK conurbations. Atmospheric Environment, 41(38), 8455-8467.

McPherson, G., Simpson, J. R., Peper P. J., Maco, S. E., and Xiao, Q. (2005, December). Municipal forest benefits and costs in five U.S. cities. Journal of Forestry, 103 (8), 411-416.

Takahashi, M., Higaki, A., Nohno, M., Kamada, M., Okamura, Y., Matsui, K., et al. (2005, November). Differential assimilation of nitrogen dioxide by 70 taxa of roadside trees at an urban pollution level. Chemosphere, 61(5), 633-639.

U.S. Department of Agriculture Forest Service Northeastern Research Station (2005). “Urban Forest Effects Model.” <http://www.ufore.org>. Cited 14 May 2009.

Special thanks to:

Brad Arndt
Urban Forest Initiative Coordinator
City of Somerville

Ellen Schneider
Landscape Project Manager
City of Somerville